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**WORKING PAPER**

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**“The price of cost-effectiveness thresholds”**

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# The price of cost-effectiveness thresholds\*

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## Abstract

Health systems around world are increasingly adopting cost-effectiveness (CE) analysis to inform decisions about access and reimbursement. We study how CE thresholds imposed by a health plan for granting reimbursement affect drug producers' pricing incentives and patients' access to new drugs. Analysing a sequential pricing game between an incumbent drug producer and a potential entrant with a new drug, we show that CE thresholds may have adverse effects for payers and patients. A stricter CE threshold may induce the incumbent to switch pricing strategy from entry accommodation to entry deterrence, limiting patients' access to the new drug. Otherwise, irrespective of whether entry is deterred or accommodated, a stricter CE threshold is never pro-competitive and may in fact facilitate a collusive outcome with higher prices of both drugs. Compared to a *laissez-faire* policy, the use of CE thresholds can only increase the surplus of a health plan if it leads to entry deterrence in which the price reduction by the incumbent necessary to deter entry outweighs the health loss to patients not getting access to the new drug.

*Keywords:* Pharmaceuticals; Health Plans; Cost-effectiveness analysis; ICER; Therapeutic competition

*JEL Classification:* I11; I18; L13; L65

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# 1 Introduction

Rising pharmaceutical expenditures are becoming a pressing concern in many countries as biomedicine advances new treatment opportunities for severe and rare diseases. Governments and health insurance plans are increasingly adopting health technology assessment to inform decisions about access, reimbursement, and drug prices. These assessments often include a cost-effectiveness (CE) analysis in which the incremental costs and benefits of a new treatment are measured relative to an existing baseline treatment. This incremental CE ratio (ICER) allows governments and insurers to assess the net value-added of a new treatment. If the incremental cost per unit of health gain is sufficiently small, the new treatment is more likely to be included in the health plan and granted reimbursement. In this way, the CE threshold reflects the government's willingness-to-pay for a new treatment, introducing value-based pricing in which prices of new drugs are associated with treatment effects learned from clinical trials (Lakdawalla, 2018). A key rationale for a stricter CE threshold is to reduce health care spending by exercising downward pressure on drug prices (Jena and Philipson, 2013, and Berdud et al., 2020).

An important characteristic of ICER is its anchoring to the price of the baseline (incumbent) treatment. For a given health gain of a new drug, the maximum price accepted by the health insurer (government or private plan) will be increasing in the drug price of the incumbent drug. Therefore, if the currently used treatment becomes more expensive (cheaper), the maximum price that can be charged by the producer of the new drug (entrant) automatically increases (decreases). Thus, the use of CE thresholds often works as an implicit price control on new drug treatments.<sup>1</sup> With the progress of advanced medicine, this role of the incumbent drug in CE analysis is important, yet overlooked, in studies of value-based pricing of new drugs.

New and improved drug treatments arrive sequentially, often allowing the latest patented drug only a few years before its incumbency position is threatened by a new entrant. Recent innovations of new Hepatitis C (HCV) drugs illustrate this pattern. Roediger et al. (2019) review three recent generations of these drugs. The first generation of HCV drugs dominated until 2010, but with the arrival of the second generation in 2011, these saw a sharp decline in market shares. The second-generation drugs had far better response rates for some types

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<sup>1</sup>The ICER is typically used as a guide for pricing. For example, the UK's National Institute for Health and Clinical Excellence recommends that every new drug approved produces at least one additional QALY for every £30,000 that it costs.

of patients. When the third generation were launched from 2014 and onwards, the second generation had already established itself as the baseline treatment for HCV patients.

With frequent replacements of baseline treatments, drug companies need to be forward-looking in their price setting. Even if a patented drug currently enjoys a dominant incumbency position, its price does not only determine the drug producer's current profit, it may also define the unit cost of the best alternative treatment when the ICER of the next drug to enter is calculated. Often, this happens long before the incumbency is threatened by patent expiration, as illustrated by the HCV case above.

A recent example of sequential assessment is new therapies for patients with spinal muscular atrophy (SMA). Biogen's Spinraza was the first treatment of this condition to be approved, in 2016 by the US Food & Drug Administration and in 2018 by the European Medicines Agency. Due to lack of baseline treatment, the health technology assessments of Spinraza used real-world care of patients as a comparator to calculate ICER. In Norway, the regional health authorities reached an agreement with Biogen in 2018 which provided access to the drug. Three years later, Novartis entered with a competing drug Zolgensma, but in this case the health technology assessment could use Spinraza as an indirect comparator, instead of the real-world care alternative. Thus, the pricing of Spinraza had a direct impact on which price of Zolgensma that would meet the CE threshold.

In this paper we study the impact of implementing CE analysis as a means for regulating access to new drug therapies in a health plan, focusing on how this policy affects the pricing decisions by the drug producers. Since the ICER depends on the prices of the existing and new drug treatments and not the actual production costs, this means that the ICER and thus also the inclusion decision are endogenously determined by the drug producers' price setting. To capture the strategic effects of a CE policy for inclusion, we model a sequential pricing game between an incumbent offering a baseline treatment and a potential entrant offering a new and potentially better drug treatment.

Based on this set-up we derive several novel and counter-intuitive results. First, for a sufficiently strict CE threshold, the scope for entry is larger the smaller the therapeutic benefit offered by the new drug. A lower threshold reduces the incumbent's profits under entry accommodation, while it increases the incumbent's profits under entry deterrence. Thus, a sufficiently strict CE threshold might induce the incumbent to switch from an entry accommodating to an entry deterring pricing strategy. The latter option is relatively more profitable if the potential

entrant has developed a drug with a higher quality, which would make it a stronger competitor in case of entry. Second, a stricter CE threshold can lead to lower drug prices only if it switches the equilibrium outcome from entry accommodation to entry deterrence. Otherwise, whether entry is deterred or accommodated in equilibrium, a stricter CE threshold is never pro-competitive – it has either no effect on drug prices or leads to a price increase. In the latter case, CE thresholds serve as a collusion facilitating mechanism which benefits the entrant.

From a policy perspective, therefore, our results do not lend strong support to the use of a CE threshold as a criterion for drug market access. Compared to a *laissez-faire* policy, where inclusion of a new drug in the health plan is granted automatically whenever it is profitable for the producer to enter the market, the use of a CE threshold as a criterion for drug inclusion might increase the health plan’s surplus only if it leads to entry deterrence. The rationale behind the use of a CE threshold seems to rely on the implicit assumption that prices of the baseline treatment are exogenous and do not take into account future competition from new treatments. However, we would claim that such an assumption might be overly naïve. Potential entrants will often appear long before the incumbent’s drug is off-patent and subjected to generic competition.

The rest of the paper is organised as follows. In the next section, we relate our study to the existing literature. In Section 3, we present the model. In Section 4, we characterize the subgame perfect equilibrium of the model, and in Section 5 we analyse the effect of CE-thresholds on prices and access to the new drug. In Section 6 we discuss policy implications, before offering some concluding remarks in Section 7. Proofs of the propositions are provided in the Appendix at the end of the paper.

## 2 Related literature

There is a vast literature on the use of CE analysis in allocating health care resources efficiently.<sup>2</sup> This literature demonstrates a solid economic foundation of using such analysis to guide medical decision making after a drug therapy or medical technology is in place, which is a key reason why CE thresholds for inclusion in the health plan have become a widespread practice, especially in European countries.<sup>3</sup>

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<sup>2</sup>See, e.g., Gold et al. (1996), Garber (2000), Drummond et al. (2015).

<sup>3</sup>Two different approaches are used to derive optimal CE thresholds for inclusion in the health plan, see, e.g., Gold et al. (1996), Claxton et al. (2015) and Sampson et al. (forthcoming). With the ‘demand-side’ approach, the optimal threshold reflects the willingness-to-pay for health gains, whereas with the ‘supply-side’ approach,

However, much less attention has been devoted to the incentives that CE thresholds for inclusion in the health plan impose on producers. Indeed, the approach taken by the above mentioned literature is that the health gains and costs of existing and new treatments are exogenously given. As pointed out by a few recent studies, this is a naïve and unrealistic assumption. The use of CE thresholds for inclusion in a health plan is likely to affect incentives both for innovation and pricing, and thus impacting both static and dynamic efficiency.

Jena and Philipson (2007) study the impact of CE analysis on the incentives for getting new technologies to the market, providing empirical evidence from a case study on HIV/AIDS. They argue that CE thresholds, by being implicit price controls, favour technologies from which the incremental static benefits exceed the associated costs. However, this inclusion criteria does not take into account dynamic incentives. Current CE thresholds could promote innovation when they function as price floors guaranteeing innovators the social value of their discoveries. Jena and Philipson (2008) provide a formal model of adoption of new technologies based on CE analysis and show that such a policy may have adverse effects on innovation incentives. They argue that CE analysis is closely related to the consumer surplus it generates and thus in conflict with policies that stimulates producer surplus and innovation, such as patent policy. Thus, CE analysis should be modified to account for dynamic efficiencies, implying less strict thresholds. Using an illustrative sample of technologies, they show that strict CE thresholds have adverse effects on dynamic efficiency, with the median technology having an appropriation of about 15 percent of the total surplus.

The paper by Jena and Philipson (2013) is closer to our study as they focus on the pricing incentives that CE thresholds impose on producers. The key point is that if the CE analysis reflects prices set optimally by the producers rather than production costs, then observed CE levels will depend on how producers' pricing responds to CE policies. Similar to our study, they find that when CE is endogenously determined via producers' price setting, policy aimed at lowering spending and improving overall CE may paradoxically raise spending and lead to adoption of more resource-costly treatments. Jena and Philipson (2013) illustrate this point empirically by using data on public coverage decisions in the United Kingdom.

While the study by Jena and Philipson (2013) is close to ours at the more general level, their approach is quite different. They assume a probabilistic adoption ('listing'), allowing

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the threshold is set to reflect the opportunity cost of introducing a new treatment in the presence of a fixed health care budget.

both the drug price and the CE threshold to affect the probability of being introduced as a treatment option in the health plan. The producer chooses a monopoly price, where the elasticity of expected demand determines the mark-up on marginal costs. Since the threshold affects the elasticity of expected demand, via the adoption probability, they are able to explore the relationship between the threshold, the drug price, and the expected drug expenditure. Thus, their study does not investigate the strategic game between an incumbent and a potential entrant, which is the key focus in our study, but considers instead a single monopoly producer.

Probabilistic adoption is also assumed by Levaggi (2014). The probability of being reimbursed depends on the price, which determines the expected cost effectiveness of the new drug. In her analysis, the threshold is exogenous, given by the new drug's expected treatment effect. The producer of the new drug sets a monopoly price, taking into account the effect of the price on the probability of being adopted ('listed'). Although this allows the benefit produced by a new drug to be equally shared with the payer, probabilistic adoption is always *ex post* inefficient since the drug might be rejected even if the ICER is below the threshold. Berdud et al. (2021) extend this line of research by analysing the impact of thresholds within a Nash-bargaining framework. The drug price is determined by Nash-bargaining between the payer and the producer. They assume that the payer can freely choose the cost-effectiveness threshold, and the buyer will do so to truncate the set of prices available to the bargainers. As in Levaggi (2014), this comes with a cost to the payer by having to turn down new drugs that are *ex post* efficient to introduce in the health plan.

Our paper differs substantially from these studies in that we focus on competition and the strategic interaction between an incumbent producer and a potential entrant in the presence of CE thresholds. To our knowledge, the strategic pricing game introduced by the CE analysis has not yet been studied in the existing literature. The above-mentioned studies focus exclusively on monopoly pricing. Our approach allows for several novel results on (unintended) effects of CE thresholds due to strategic pricing. This includes the entry deterring or accommodating pricing strategies by the incumbent, but also the subsequent effects on drug prices and expenditures for payers and access to new medical treatments for patients.

Our framework for analysing competition in the pharmaceutical market builds on a strand of literature that uses a spatial framework in which drugs are (potentially) both horizontally and vertically differentiated.<sup>4</sup> Among these studies, the general set-up in our paper relates most

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<sup>4</sup>See, e.g., Brekke et al. (2007), Miraldo (2009), Bardey et al. (2010), Bardey et al. (2016), Brekke et al.

closely to the formulation in Miraldo (2009) and Brekke et al. (2022). A key assumption in these models is that a given therapeutic class contains several drugs with different active ingredients. Although these drugs are not perfect substitutes, empirical research supports the assumption that treatment effects can be sufficiently overlapping to establish therapeutic competition.<sup>5</sup> While our paper builds on the modelling framework of this strand of literature, none of these studies analyse the impact of CE analysis nor consider a sequential pricing game between an incumbent and a potential entrant, which is key to our analysis.

Finally, our paper relates to the literature on limit pricing. The seminal paper by Bain (1949) argues that an incumbent firm can discourage entry by charging a low price. This original idea of limit pricing was later rejected as it did not satisfy the subgame perfection criterion; the incumbent has an incentive to increase its price if entry occurs, which makes a low pre-entry price not credible.<sup>6</sup> The lack of commitment is the key issue. Our paper introduces regulation as a commitment device for the incumbent to prevent entry. By adjusting the pre-entry price, the incumbent can manipulate the ICER and thus the inclusion criterion for a new drug producer. A similar mechanism has been analysed by Bergman and Rudholm (2003). They argue that the price regulation present in the Swedish pharmaceutical market introduces a ‘ratchet’ effect for the incumbent producer, as they cannot increase prices post entry. They find evidence of limit pricing in relatively smaller markets where the brand-name producers prevent entry by generics by lowering prices prior to patent expiration.<sup>7</sup> Our paper contributes to this small literature on limit pricing in pharmaceutical markets by considering a different regulatory mechanism (i.e., the CE thresholds) in a context of therapeutic competition between on-patent drugs, and our analysis produces a set of novel results as explained in the previous section.

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(2016), González et al. (2016) and Brekke et al. (2022).

<sup>5</sup>Kanavos et al. (2007) analysed the existence of competition between branded statins in European markets prior to patent expiry. Their results are consistent with potential price sensitivity in the branded market for statins. Danzon and Epstein (2012) found that prices of new drugs are influenced by prices of other products in the same class. Lu and Comanor (1998) analysed therapeutic competition and found that launch prices of drugs that are closer substitutes to existing brands are typically priced at comparable levels. In addition, they found that the number of branded substitutes has a substantially negative effect on launch prices.

<sup>6</sup>Later papers, starting with Milgrom and Roberts (1982), introduced asymmetric information where the pre-entry price signals the cost type of the incumbent. While limit pricing is an equilibrium strategy in these studies, the price itself is not what deters entry but rather the underlying cost or capacity signalled by the pre-entry pricing of the incumbent.

<sup>7</sup>The paper is mainly empirical, but contains an appendix with a model of limit pricing under price regulation using linear demand.



### 3 Model

Consider a therapeutic market for on-patent prescription drugs where patients are uniformly distributed on a unit line with total mass equal to one. The line can be interpreted as a ‘disease space’ in which the distance between a drug and a patient reflects the degree of therapeutic mismatch. Each patient in the market needs one unit of drug treatment, and drug prescription choices are made by a physician who prescribes what is considered the most appropriate drug from the available choice set, which consists of the drug(s) approved by the relevant health plan. When making this decision, the prescribing physician takes into account both the patient’s health benefit and the price(s) of the drug(s). Consider a drug denoted by  $i$ , which is located at  $z_i$ , has therapeutic quality  $v_i$  and costs  $p_i$ . If one unit of this drug is prescribed to a patient located at  $x \in [0, 1]$ , the utility assigned to this choice by the prescribing physician is

$$u_i(x) = v_i - t|x - z_i| - \beta p_i, \quad (1)$$

where  $t > 0$  measures the relative importance of therapeutic mismatch, and  $\beta$  measures the price sensitivity of the physician’s prescription choices. We assume that  $\beta \in (0, 1)$ , which implies that the physician gives relatively more importance to patients’ health benefits than to the health plan’s expenditures when making drug prescription choices.<sup>8</sup>

We consider a case in which there are potentially two drugs approved by the health plan and thus available in this particular therapeutic market. An incumbent producer offers a drug, denoted by  $I$ , which is located at one of the endpoints and has quality  $v_I$ . A potential entrant has developed a new drug, denoted by  $E$ . This drug has quality  $v_E > v_I$  and therapeutic characteristics that correspond to a location at the other endpoint. Thus, the new drug is both horizontally and vertically differentiated from the existing one.

The potential entrant will gain access to the market only if the new drug passes a cost-effectiveness (CE) threshold. More specifically, the price of the drug must be such that the cost per additional unit of improvement in expected health benefits is below some threshold  $k > 0$ .<sup>9</sup> Since the expected (average) health benefit for drug  $i$  is given by  $v_i - (t/2)$ , the above described

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<sup>8</sup>Notice that the interpretation of  $\beta$  may include patient copayments in the form of coinsurance. All else equal, a higher coinsurance rate implies a higher value of  $\beta$ .

<sup>9</sup>This is in line with current practice. For example, the UK’s National Institute for Health and Clinical Excellence recommends that every new drug approved produce at least one additional QALY for every £30,000 that it costs.

cost-effectiveness criterion translates to the condition

$$\frac{p_E - p_I}{\Delta v} \leq k, \quad (2)$$

or

$$p_E \leq p_I + k\Delta v, \quad (3)$$

where  $\Delta v := v_E - v_I > 0$  measures the improvement in expected health benefits (often measured in QALYs) offered by the new drug. We will interchangeably refer to (3) as the *CE condition* or the *CE threshold*.

We assume that variable production costs are given by a constant marginal cost  $c > 0$ , which for simplicity is assumed to be equal for the two drugs. Additionally, the potential entrant has to pay a fixed cost  $f$  to enter the market. Thus, in case of entry, profits are given by

$$\pi_I = (p_I - c) y_I \quad (4)$$

and

$$\pi_E = (p_E - c) y_E - f, \quad (5)$$

where  $y_i$  is demand for drug  $i = I, E$ .<sup>10</sup>

Given all of the above assumptions, the entry decision results from the following three-stage game:

1. The incumbent sets a price  $p_I$ .
2. The potential entrant decides whether to enter with a price  $p_E$ , that satisfies the CE condition in (3), or not to enter the market.
3. Physicians prescribe drugs from the available choice set.

The sequential order of price setting relies on an implicit assumption that the incumbent is able to commit to a price that cannot easily be changed after the entry decision has been made at the subsequent stage of the game. Such commitment makes sense in the particular context we are studying, since price changes have to be approved by the health plan. In particular, the health plan is unlikely to sanction a price increase that cannot be justified by exogenous cost

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<sup>10</sup>We assume that  $v_i$  is sufficiently large (for  $i = I, E$ ) to ensure full market coverage in equilibrium.

increases or other exceptional circumstances. Thus, in contrast to an ordinary market with free pricing, the particular institutional features of on-patent pharmaceutical markets are such that price reductions cannot easily be reversed. Furthermore, the application of a CE threshold for new drugs also places constraints on *ex post* price adjustments.

Finally, in order to ensure existence of all candidate equilibria for any  $k > 0$ , we assume that the quality difference between the drugs is not too high; more specifically, we assume that

$$\Delta v \leq \begin{cases} \min \left\{ \frac{t}{1-\beta k}, 3t \right\} & \text{if } k < \frac{1}{\beta} \\ 3t & \text{if } k \geq \frac{1}{\beta} \end{cases}. \quad (6)$$

## 4 Analysis

In this section we solve the game by backwards induction, looking for the subgame perfect Nash equilibrium (SPNE).

### 4.1 Drug demand

At the last stage of the game, the prescribing physician has either one or two drugs in his prescription choice set. In the latter case, which occurs if the potential entrant decided to enter the market, drug prescription choices are made such that (1) is maximised for all patients. The patient for whom the physician is indifferent between prescribing the old or the new drug is located at  $\hat{x}$ , which is implicitly given by

$$v_I - t\hat{x} - \beta p_I = v_E - t(1 - \hat{x}) - \beta p_E. \quad (7)$$

The demand for the incumbent drug is consequently given by

$$y_I = \frac{1}{2} + \frac{\beta(p_E - p_I) - \Delta v}{2t}, \quad (8)$$

while  $y_E = 1 - y_I$  patients are prescribed the new drug. All else equal, the larger the quality improvement offered by the new drug, the lower is demand for the old drug. The latter drug's demand disadvantage can be mitigated by a lower price, but the magnitude of this mitigating effect depends on the price-responsiveness of drug prescription choices.

On the other hand, if the potential entrant decides not to enter the market, the incumbent producer remains a monopolist. In this case, the physicians' prescription choice set for this

particular disease consists of only one drug, and we assume that  $v_I$  is sufficiently high such that  $u_I(x) > 0$  for all  $x \in [0, 1]$ , implying that the drug will be prescribed to all patients. In the case of no entry, the demand for the incumbent drug is thus given by  $y_I = 1$ .

## 4.2 The entry decision

At the second stage of the game, the potential entrant observes the price set by the incumbent producer and decides whether to stay out of the market or to enter with a price satisfying the CE condition. This decision is determined by whether the incumbent has set a price that accommodates or deters entry. We will consider each of these cases in turn.

### 4.2.1 Entry accommodation

In case of entry, the optimal price chosen by the potential entrant is a price that solves the following constrained maximisation problem:

$$\max_{p_E} \pi_E = (p_E - c) \left( \frac{1}{2} + \frac{\beta(p_I - p_E) + \Delta v}{2t} \right) - f \quad \text{such that} \quad p_E \leq p_I + k\Delta v. \quad (9)$$

The solution to this problem yields the following best-response function:

$$p_E(p_I) = \begin{cases} k\Delta v + p_I & \text{if } p_I \leq \hat{p}_I \\ \frac{c}{2} + \frac{t + \Delta v}{2\beta} + \frac{p_I}{2} & \text{if } p_I > \hat{p}_I \end{cases}, \quad (10)$$

where

$$\hat{p}_I := c + \frac{t}{\beta} + \left( \frac{1 - 2\beta k}{\beta} \right) \Delta v. \quad (11)$$

Thus, the best-response function of the potential entrant is kinked at  $\hat{p}_I$ , such that the CE condition binds for  $p_I \leq \hat{p}_I$ .

At the first stage of the game, the incumbent chooses a profit-maximising price  $p_I$ , which can be either on the constrained or the unconstrained part of the entrant's best-response function. Suppose first that it is on the unconstrained part. We refer to this case as *unconstrained entry accommodation*. The equilibrium prices are in this case given by

$$p_I^a = c + \frac{1}{2\beta} (3t - \Delta v) \quad (12)$$

and

$$p_E^a = c + \frac{1}{4\beta} (5t + \Delta v). \quad (13)$$

These prices satisfy the CE condition if

$$k \geq \widehat{k} := \frac{1}{4\beta} \left( 3 - \frac{t}{\Delta v} \right). \quad (14)$$

A candidate equilibrium of this kind is illustrated in Figure 1, where the thick part of the curves is the potential entrant's best-response curve; i.e., the graph of (10). The corresponding profits are

$$\pi_I^a = \frac{(3t - \Delta v)^2}{16t\beta} \quad (15)$$

and

$$\pi_E^a = \frac{(5t + \Delta v)^2}{32t\beta} - f. \quad (16)$$

For the remainder of the analysis, we assume that

$$f < \bar{f} := \frac{(5t + \Delta v)^2}{32t\beta}, \quad (17)$$

implying that unconstrained entry accommodation is a feasible outcome for  $k \geq \widehat{k}$ .

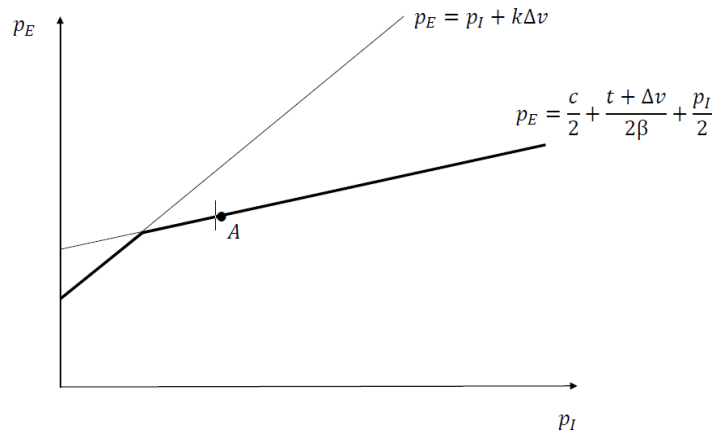


Figure 1: Unconstrained entry accommodation

Suppose instead that  $k < \widehat{k}$ , which implies that the incumbent's profit-maximising price is

on the constrained part of the entrant's best-response function. Notice that  $\partial p_E / \partial p_I = 1$  on this part of the best-response function. In other words, a one euro increase in the incumbent's price will induce a similar price increase of the entrant's drug, which means that relative drug prices remain constant. Since total demand is fixed, a price increase that keeps relative prices constant is always profitable. Consequently, the profit-maximising price on the constrained part of the entrant's best-response function is at  $p_I = \hat{p}_I$ . The equilibrium prices in this case, which we refer to as *constrained entry accommodation*, are then given by

$$\hat{p}_I^a = c + \frac{t}{\beta} + \left( \frac{1 - 2\beta k}{\beta} \right) \Delta v \quad (18)$$

and

$$\hat{p}_E^a = \hat{p}_I^a + k\Delta v. \quad (19)$$

A candidate equilibrium of this kind is illustrated in Figure 2. In this figure, point  $A$  indicates the prices under unconstrained entry accommodation, which is not feasible. The prices under accommodated entry are therefore constrained by the CE condition and indicated by point  $\hat{A}$  in the figure.

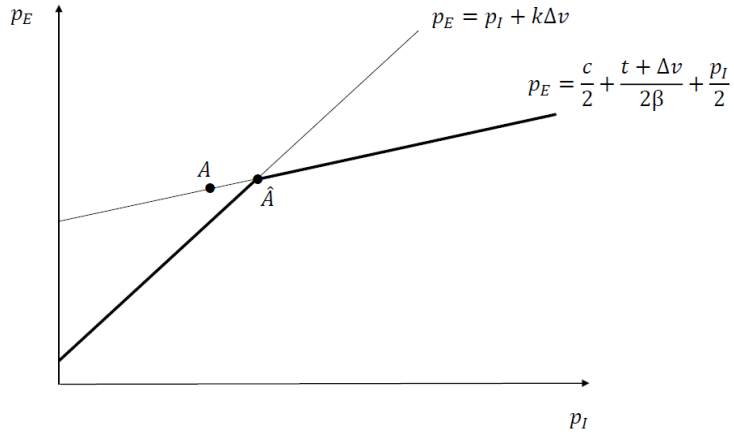


Figure 2: Constrained entry accommodation

It is worth reflecting some more on the pricing incentives introduced by a binding CE condition. Because of the one-to-one relationship between the two drug prices along the constrained

part of the entrant's best-response function, the incumbent has an incentive to implement the highest possible price pair for which the CE condition binds, as explained above. Thus, for  $k < \widehat{k}$ , the CE condition serves as a *collusion facilitating mechanism* under entry accommodation, where the prices of both drugs are higher than they would have been in the absence of a CE threshold. The corresponding profits under constrained entry accommodation are given by

$$\widehat{\pi}_I^a = \frac{(t + (1 - 2\beta k) \Delta v) (t - (1 - \beta k) \Delta v)}{2\beta t} \quad (20)$$

and

$$\widehat{\pi}_E^a = \frac{(t + (1 - \beta k) \Delta v)^2}{2\beta t} - f. \quad (21)$$

How does the level of the CE threshold ( $k$ ) affect equilibrium prices and profits under entry accommodation? The answer is given by the following Lemma:

**Lemma 1** *Under accommodated entry, (i) if  $k > \widehat{k}$ , a stricter CE threshold has no impact on prices and profits, while (ii) if  $k < \widehat{k}$ , a stricter CE threshold leads to higher prices for both drugs, and higher (lower) profits for the entrant (incumbent).*

These are discouraging results for proponents of a CE-based policy to contain drug prices. Under entry accommodation, to the extent that the implementation of a (stricter) CE threshold affects drug prices, it leads to higher instead of lower prices. If  $k < \widehat{k}$ , a stricter threshold (lower  $k$ ) will lead to a downward shift of the steeper curve in Figure 2, thus making the CE condition bind for a larger segment of the entrant's best-response curve. Because of the collusion facilitating mechanism described above, this will lead to higher prices for both drugs. Notice, however, that a reduction in  $k$  is not in the interest of the incumbent firm, despite the price increase, because it brings the equilibrium further away from the unconstrained optimum (point  $A$  in Figure 2). Instead, it is the entrant that benefits from a stricter CE threshold, because, paradoxically, it allows the firm to enter the market with a higher price.

#### 4.2.2 Entry deterrence

As long as  $f > 0$ , the incumbent can deter entry by setting a lower price; a price that is just low enough for entry to be unprofitable. Formally, the optimal entry-detering price,  $p_I^d$ , is given by

$$\pi_E \left( p_I^d, p_E \left( p_I^d \right) \right) = 0. \quad (22)$$

As for the case of entry accommodation, the optimal entry-detering price can be either on the unconstrained or the constrained part of the potential entrant's best-response function.

Suppose first that entry can be deterred by choosing a price on the unconstrained part of the best-response function. The potential entrant's maximum profit, as a function of  $p_I$ , is then given by

$$\pi_E(p_I) = \frac{(t + \Delta v + \beta(p_I - c))^2}{8t\beta} - f. \quad (23)$$

The optimal entry-detering price in this case, which we refer to as *unconstrained entry deterrence*, is given by

$$p_I^d = c - \frac{(t + \Delta v - 2\sqrt{2\beta t f})}{\beta}. \quad (24)$$

A candidate equilibrium of this kind gives the incumbent a profit of

$$\pi_I^d = \frac{2\sqrt{2\beta t f} - t - \Delta v}{\beta}. \quad (25)$$

By construction, this candidate equilibrium is feasible only if  $p_I^d \geq \hat{p}_I$ , which is true if

$$f \geq f_1 := \frac{(t + (1 - k\beta)\Delta v)^2}{2t\beta}. \quad (26)$$

A candidate equilibrium of this kind is illustrated by point  $D$  in Figure 3. Notice that unconstrained entry deterrence is a possible outcome only if unconstrained entry accommodation is feasible.



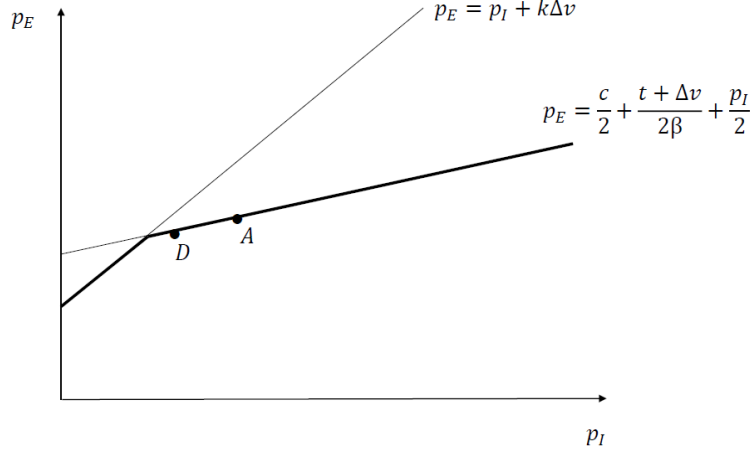


Figure 3: Unconstrained entry deterrence

Alternatively, if  $f < f_1$ , entry can only be deterred by setting a price on the constrained part of the potential entrant's best-response function. The potential entrant's maximum profits are then given by

$$\widehat{\pi}_E(p_I) = \frac{(t + (1 - \beta k) \Delta v) (p_I - c + k \Delta v)}{2t} - f. \quad (27)$$

In this case, which we refer to as *constrained entry deterrence*, the optimal entry-detering price is given by

$$\widehat{p}_I^d = c - k \Delta v + \frac{2tf}{t + (1 - \beta k) \Delta v}. \quad (28)$$

Two different versions of a candidate equilibrium of this kind are illustrated by point  $\widehat{D}$  in Figures 4a and 4b. In Figure 4a, entry deterrence is constrained by the CE condition even if unconstrained entry accommodation is feasible. In Figure 4b, on the other hand, unconstrained entry accommodation is not feasible, which in turn means that entry deterrence must also necessarily be constrained by the CE condition. In either case, the incumbent's profits under constrained entry deterrence are given by

$$\widehat{\pi}_I^d = \frac{2tf}{t + (1 - \beta k) \Delta v} - k \Delta v. \quad (29)$$

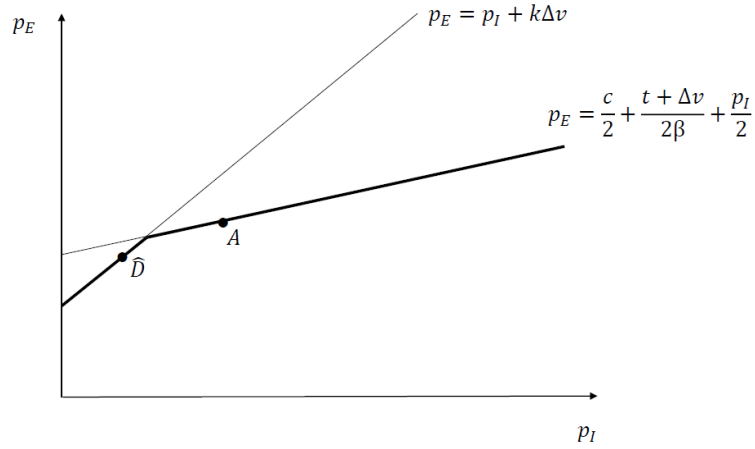


Figure 4A. Constrained entry deterrence I

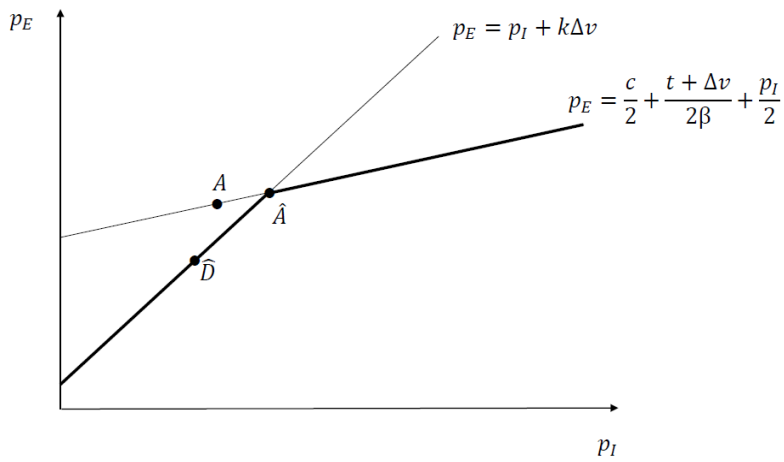


Figure 4B. Constrained entry deterrence II

The next Lemma summarises how a (stricter) CE threshold affects prices and profits under entry deterrence.

**Lemma 2** *Under entry deterrence, (i) if  $f > f_1$ , a stricter CE threshold has no effect on prices and profits, while (ii) if  $f \leq f_1$ , a stricter CE threshold leads to higher price and profits for the incumbent drug producer.*

Also in case of entry deterrence, a CE-based policy has a counterproductive effect on drug prices. If  $f$  is sufficiently low, such that the CE condition binds, a stricter threshold leads to

higher instead of lower drug prices. In this case, the reason is simply that a reduction in  $k$  makes it easier for the incumbent to deter entry; i.e., entry can be deterred at a higher price, which obviously benefits the incumbent producer, all else being equal.

### 4.3 The subgame-perfect Nash equilibrium

The previous analysis defines four candidate SPNE outcomes. At the first stage of the game, the incumbent effectively selects the most profitable among these outcomes. In order to characterise this selection, we make the following parameter definitions:

$$f_2 := \frac{1}{2t} \left( k\Delta v + \frac{(3t - \Delta v)^2}{16t\beta} \right) (t + (1 - \beta k) \Delta v), \quad (30)$$

$$f_3 := \frac{(t + (1 - \beta k) \Delta v)^2 (t - (1 - 2\beta k) \Delta v)}{4t^2\beta}, \quad (31)$$

$$f_4 := \frac{(5t + \Delta v)^4}{2048\beta t^3}. \quad (32)$$

It is also useful to note that  $f_1 = f_2 = f_4$  if  $k = \tilde{k}$ , where

$$\tilde{k} := \frac{22t\Delta v + 7t^2 - (\Delta v)^2}{32t\beta\Delta v} > \hat{k}. \quad (33)$$

With these parameter definitions, we can fully characterise the SPNE outcome as follows:<sup>11</sup>

**Proposition 1** (i) If  $k \leq \hat{k}$ , the SPNE outcome is constrained entry accommodation for  $f \leq f_3$  and constrained entry deterrence for  $f > f_3$ .

(ii) If  $k \in (\hat{k}, \tilde{k}]$ , the SPNE outcome is unconstrained entry accommodation for  $f \leq f_2$ , constrained entry deterrence for  $f \in (f_2, f_1]$ , and unconstrained entry deterrence for  $f > f_1$ .

(iii) If  $k > \tilde{k}$ , the SPNE outcome is unconstrained entry accommodation for  $f \leq f_4$  and unconstrained entry deterrence for  $f > f_4$ .

Two basic observations can immediately be made. The first observation is that each of the four possible outcomes can appear as an equilibrium outcome, depending on parameter values. The second observation is that the equilibrium configuration is characterised by a clear and intuitive pattern. All else equal, a higher entry cost ( $f$ ) increases the scope for entry deterrence instead of entry accommodation, whereas a stricter CE threshold (lower  $k$ ) increases the scope

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<sup>11</sup>A proof is given in the Appendix.

for the CE condition to bind in equilibrium. The results in Proposition 1 are illustrated in Figure 5 for a particular numerical example, where  $t = 2$ ,  $\beta = 0.6$ ,  $\Delta v = 2$  and  $c = 1$ . Different parameter values yield a qualitatively similar picture.

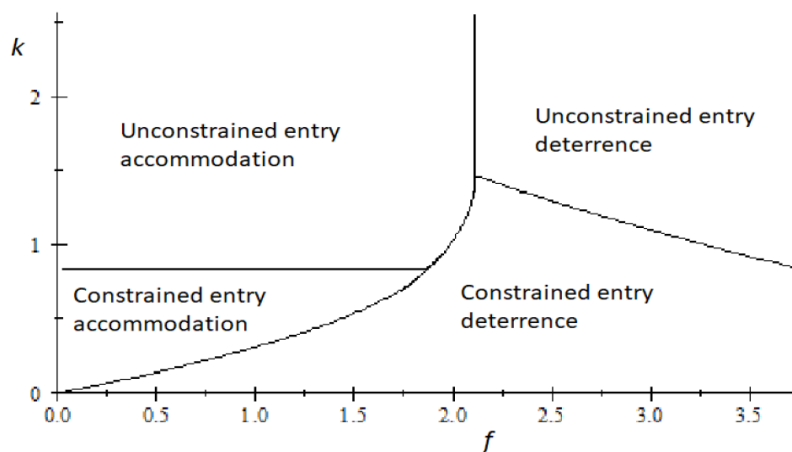


Figure 5. SPNE outcomes

## 5 Effects of CE thresholds on entry and drug prices

The application of a cost-effectiveness threshold for market access can in principle have two different effects in the context of our analysis. First, it can affect the likelihood that a new drug enters the market. Second, regardless of whether a new drug enters or not, it can affect the drug price(s) in the market. In this section we will consider each of these effects in turn.

### 5.1 CE thresholds and entry of new drugs

Regarding the likelihood of entry, Figure 5 illustrates that the application of a CE threshold can facilitate the adoption of an entry deterring pricing strategy by the incumbent producer. If  $f \leq f_4$ , the equilibrium outcome is entry accommodation in the absence of a CE threshold (which can formally be thought of as  $k \rightarrow \infty$ ). However, a sufficiently strict CE condition might incentivise the incumbent to switch from an entry accommodating to an entry deterring pricing strategy. In Figure 5, the SPNE outcome is actually always entry deterrence if  $k$  is sufficiently low, as long as  $f > 0$ . And notice that entry is deterred not because of the CE threshold itself,

but because the existence of a CE threshold facilitates an entry deterring pricing strategy by the incumbent.

Perhaps the most interesting aspect of the entry deterring effect of a CE threshold is how this effect depends on the drug quality improvement offered by the potential entrant. Our next Proposition highlights this aspect.<sup>12</sup>

**Proposition 2** *For a sufficiently strict CE threshold, the scope for entry is larger the smaller the therapeutic benefit offered by the new drug.*

The intuition for this result follows from the analysis in Section 4. A lower value of  $k$  reduces the incumbent's profits under constrained entry accommodation (Lemma 1) while it increases the incumbent's profits under constrained entry deterrence (Lemma 2). Thus, a sufficiently strict CE threshold might induce the incumbent to switch from an entry accommodating to an entry deterring pricing strategy. The latter option is relatively more profitable if the potential entrant produces a drug with a higher quality, which would make it a stronger competitor in case of entry. Thus, the lower (higher) the quality of the new drug, the less (more) likely it is that it will be deterred from entering the market when  $k$  is sufficiently low.

Once more, the use of cost-effectiveness thresholds is shown to have potentially counter-productive effects when we take into account the incentives for strategic behaviour by the incumbent. If the cost-effectiveness threshold is sufficiently strict, then the use of such thresholds reduces the probability of entry for drugs that offer a larger increase in therapeutic benefit, compared to drugs with a smaller therapeutic value added, all else equal. Paradoxically, this is the opposite of what is normally considered to be the intended effects of using a market access policy based on CE thresholds.

## 5.2 CE thresholds and drug prices

The effects of CE thresholds on equilibrium drug prices within each type of equilibrium were described in Lemmas 1 and 2. When we also consider the possibility that a change in the threshold might change the type of equilibrium, the overall relationship between the CE threshold and equilibrium drug prices are given as follows:<sup>13</sup>

**Proposition 3** *A stricter CE threshold can lead to lower drug prices only if it switches the equilibrium outcome from entry accommodation to entry deterrence. Otherwise, whether entry*

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<sup>12</sup>A proof is given in the Appendix.

<sup>13</sup>A proof is given in the Appendix.

is deterred or accommodated in equilibrium, a stricter CE threshold is never pro-competitive; it has either no effect on drug prices or leads to a price increase.

The explanation for this result follows from the previously explained intuition for Lemmas 1 and 2. When seen in conjunction with Proposition 1, it appears that the application of a CE threshold for drug approvals can induce lower drug prices only if the entry cost is sufficiently low ( $f \leq f_4$ ), and only if it deters entry of new drugs. Thus, any potentially price-reducing effect of CE thresholds comes at the cost of lower therapeutic benefits.

## 6 Policy implications

From a policy perspective, the results derived in the previous sections do not seem to lend strong support to the use of a cost-effectiveness threshold as a criterion for drug market access. In fact, a natural question to ask is whether the use of CE thresholds is ever preferable to a *laissez-faire* policy, where inclusion of a new drug in the health plan is automatically granted whenever it is profitable for the producer to enter the market. When answering this question, we will assume that the policy objective is to maximise the surplus of the health plan, given by total health benefits to patients net of drug purchasing costs. If both drugs are included in the health plan, this surplus is given by

$$S(I, E) = \int_0^{y_I} (v_I - p_I - tx) dx + \int_{y_I}^1 (v_E - p_E - t(1-x)) dx. \quad (34)$$

On the other hand, if the incumbent remains a monopolist in the market, the health plan's surplus is given by

$$S(I) = v_I - p_I - \frac{t}{2}. \quad (35)$$

Under a *laissez-faire* policy, the SPNE outcome is (unconstrained) entry deterrence for  $f > f_4$ . In this case, the use of a CE threshold can only switch the outcome to constrained entry deterrence, if  $k$  is set sufficiently low (cf. Figure 5). However, this would only lead to an increase in the price of the incumbent drug (Lemma 2), which obviously reduces the health plan's surplus.

On the other hand, if  $f \leq f_4$ , implying that the SPNE outcome is (unconstrained) entry accommodation under a *laissez-faire* policy, the use of a CE threshold can switch the outcome either to constrained entry accommodation or to constrained entry deterrence, depending on

the chosen value of  $k$ . In former case, the health plan's surplus would decrease for two different reasons. First, we know from Lemma 1 that this would lead to higher prices for both drugs, thus increasing the costs of the health plan. Second, a comparison of (18) and (19) reveals that the price difference between the drugs ( $p_E - p_I$ ) would also increase, which implies that demand would shift in the direction of the lower-quality drug, thus increasing the treatment distortion caused by the higher price for the higher-quality drug, leading to higher mismatch costs and therefore lower overall health benefits.

Thus, the only possibility for the use of a CE threshold to increase the health plan's surplus is if such a policy switches the SPNE outcome from (unconstrained) entry accommodation to (constrained) entry deterrence. The benefit of such a policy would be that it induces the incumbent to switch from a high-price (accommodation) to a low-price (deterrence) strategy, thus reducing the costs of the health plan. On the other hand, such a policy would exclude the higher-quality drug from the market, thus reducing the total health benefits. Using the previously derived equilibrium expressions, the change in the health plan's surplus resulting from a switch from unconstrained entry accommodation to constrained entry deterrence is given by

$$\widehat{S}(I) - S(I, E) = \frac{(t + (1 - \beta k) \Delta v) \Phi - 128\beta t^2 f}{64t\beta (t + (1 - \beta k) \Delta v)}, \quad (36)$$

where

$$\Phi := (86 - 15\beta) t^2 + ((6 - 7\beta) \Delta v - 4t - 38t\beta + 64kt\beta) \Delta v. \quad (37)$$

It is easily confirmed that (36) is positive, implying that the effect of lower prices dominates, for a subset of the relevant parameter space. Overall, this leads us to the following answer to our original question:

**Proposition 4** *Compared to a laissez-faire policy, the use of a CE threshold as a criterion for drug inclusion might increase the health plan's surplus only if it leads to entry deterrence.*

In other words, basing drug inclusion decisions on a CE threshold is potentially beneficial only if inclusion is never granted. This is arguably a rather paradoxical result and might serve as an illustration of the potential problems with such a policy. The root of the problem is that the inclusion criterion depends directly on the prices of existing drugs in the market. The rationale behind the use of CE thresholds therefore relies on the implicit assumption that existing drug prices are exogenous. However, such an assumption might be overly naïve, since the presence of

a (sufficiently strict) CE threshold gives incumbent drug producers an incentive to strategically adjust their prices *ex ante* in the face of potential entry from new drugs which represent a therapeutic alternative to existing ones.<sup>14</sup>

There are several alternative inclusion criteria that would generally outperform a criterion based on CE thresholds. To give one example, suppose that the incumbent producer and the potential new entrant were invited to compete for an exclusive contract by submitting price bids, with the contract being awarded to the drug that yields the higher surplus for the health plan. If  $f < \Delta v$ , such a contest would be won by the new entrant with an equilibrium bid of  $p_E = c + \Delta v$ , which would yield a health plan surplus of

$$S(E) = v_I - c - \frac{t}{2}, \quad (38)$$

which is the value of the health plan's outside option (awarding the exclusive contract to the incumbent instead of the new potential entrant). In contrast, if the health plan uses an inclusion criterion based on a CE threshold, the maximum surplus that can be achieved is found by inserting the equilibrium price under constrained entry deterrence, (28), into (35), yielding

$$S(I) = v_I - c - \frac{t}{2} + k\Delta v - \frac{2tf}{(t + (1 - k\beta)\Delta v)}. \quad (39)$$

Comparing (38) and (39), it is easily confirmed that  $S(E) > S(I)$  for all values of  $k$  such that  $f > f_3$ , which is needed to induce entry deterrence (cf. Proposition 1). Thus, for  $f < \Delta v$ , competition for an exclusive contract would always yield a higher health plan surplus than using an inclusion criterion based on an optimally chosen CE threshold.

Competition for an exclusive contract is of course only one of several different options available to the health plan. Using a similar theoretical framework, Brekke et al. (2022) analyse the relative merits of both exclusive and non-exclusive contracts, where the drug producers are allowed to compete for these contracts using either uniform pricing or two-part tariffs, and we refer the interested reader to that paper for an in-depth analysis of these different options. Although the optimal choice is likely to depend on the specific characteristics of drug demand and therapeutic benefits, our main claim is that, instead of basing inclusion decisions on a criterion that depends on existing prices in the market, a health plan would generally be better off letting

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<sup>14</sup>Note that the strategic adjustment by the incumbent is always a price reduction compared to the monopoly price under no threat of entry. Thus, it is likely that a health plan is willing to accept such a price adjustment for the baseline treatment by the incumbent.



incumbent drug producers compete with potential new entrants for (continued) inclusion in the plan.

## 7 Concluding remarks

Cost-effectiveness (CE) analysis has become widely popular among health insurers to assess whether a new technology or medical treatment should be included in the plan and thus granted reimbursement. By using an existing baseline treatment as a benchmark for computing the incremental health gains and costs of a new treatment, the use of CE thresholds implies an implicit price control on new treatments.

The novelty of our study is the analysis of the pricing game between an incumbent and a potential entrant when CE thresholds are used for inclusion of new treatments in the health plan. A key insight is that CE thresholds may be counterproductive in providing access to new and better treatments to patients and for inducing lower prices and cost savings for the insurer. The main reason for this somewhat counterintuitive result is that the incumbent has an incentive to manipulate the CE threshold by strategically adjusting the price of the existing baseline treatment in presence of a potential entrant.

More precisely, we show that a (stricter) CE threshold may induce the incumbent to switch pricing strategy from entry accommodation to entry deterrence, resulting in the new treatment being foreclosed from the market. Otherwise, if the pricing strategy is either deterrence or accommodation, a (stricter) CE threshold is never pro-competitive. It has either no effect on drug prices or may in fact facilitate a collusive outcome with higher prices of both drugs in the case of entry accommodation. Compared to a *laissez-faire* policy, the use of CE thresholds can only increase the surplus of a health plan if it leads to entry deterrence in which the price reduction by the incumbent necessary to deter entry outweighs the health loss to patients who do not get access to the new drug. Thus, there are likely other mechanisms than CE thresholds that ensure lower prices and better access to new treatments, as illustrated by our analysis of exclusive contracts.

By way of conclusion, we would like to make a few remarks. First, our results are derived from a sequential pricing game, which implicitly relies on the assumption that the incumbent producer cannot easily make *ex post* price adjustments. This assumption is justified by the particular institutional context of our analysis, where price adjustments have to be approved

by the regulator (health plan). In three out of the four possible equilibria, the incumbent's *ex post* incentives for price adjustments would imply either price increases or a violation of the CE condition for entry. The only exception is the case of unconstrained accommodated entry, in which the CE condition does not bind and the incumbent would have an incentive to reduce the price *ex post*. However, if we allow for *ex post* price adjustments in this case, implying that the simultaneous-move price equilibrium would be played under unconstrained entry accommodation, this would not qualitatively affect the equilibrium configuration given by Proposition 1 and illustrated in Figure 5. Thus, our analysis essentially relies on the assumption that the regulator would not sanction *ex post* price adjustments that either lead to higher prices or that violate the restriction on relative prices given by the CE condition.

Second, our study does not address how the use of CE thresholds affects the innovation incentives of the drug producers. This is an important topic of pharmaceutical policy design in general (see, e.g., Lakdawalla and Sood, 2009, Levaggi et al., 2017, and Agha et al., 2022), but beyond the scope of this paper and left for future research. The fact that CE thresholds work as an implicit price control on new treatments might suggest that the patent rent for an average innovation is lower than under a *laissez-faire* policy (i.e., inclusion in plan as long as entry is profitable). However, our analysis has shown that the opposite might be the case if the use of CE thresholds gives the incumbent an incentive for constrained entry accommodation, in which case the price reduction of the incumbent is smaller than in the absence of a CE threshold, leaving higher profits for the entrant. The use of such thresholds might also affect producers' incentives to spend resources on drastic versus minor ('me-too') innovations, since the probability of successful entry depends on the therapeutic benefit offered by the new drug. Once more, our analysis has shown that the effect of CE thresholds is far from obvious and often counterintuitive, with the probability of entry being higher for innovations with smaller therapeutic benefit under sufficiently strict CE thresholds (cf. Proposition 2). Thus, the net effects on innovation incentives of the widespread use of CE analysis by health plans are far from straightforward and would need a careful analysis that explicitly takes into account the innovation stage.

Finally, we have not derived the socially optimal policy for assessing new treatments or technologies for inclusion in a health plan. Instead, we have focused on possible adverse and unintentional effects of the current schemes relying heavily on CE analysis. Our policy analysis is only partial in the sense that we show under which circumstances CE thresholds may improve the

surplus compared to the case of no regulatory restrictions. We have also pointed at competition for exclusive contracts as one example of a mechanism that is likely to improve the surplus of a health plan maximising the health gains to patients net of the drug expenditures. There may be other mechanisms that improve the social surplus, including different payment schemes like two-part tariffs. However, a full welfare analysis that ends with an optimal policy is beyond the scope of this paper and thus left for future research.

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## Appendix

### Proof of Proposition 1

(i) Suppose that  $k \leq \hat{k}$ , which means that if the incumbent wants to accommodate entry, the optimal price is given by  $\hat{p}_I^a$  in (18). Furthermore, a comparison of (17) and (26) shows that

$$f_1 - \bar{f} = \frac{(9t + 5\Delta v - 4k\beta\Delta v)(3\Delta v - t - 4k\beta\Delta v)}{32t\beta} \geq 0 \text{ if } k \leq \hat{k}, \quad (\text{A1})$$

which implies that, if the incumbent wants to deter entry, the optimal price is given by  $\hat{p}_I^d$  in (28). Thus, if  $k \leq \hat{k}$ , the incumbent chooses between constrained entry accommodation and

constrained entry deterrence. A comparison between (20) and (29) shows that

$$\widehat{\pi}_I^a - \widehat{\pi}_I^d = \frac{(t - (1 - 2\beta k) \Delta v) (t + (1 - \beta k) \Delta v)^2 - 4t^2 \beta f}{2t\beta (t + (1 - \beta k) \Delta v)} \geq (<) 0 \text{ if } f \leq (>) f_3. \quad (\text{A2})$$

Thus, if  $k \leq \widehat{k}$ , the SPNE outcome is constrained entry accommodation for  $f \leq f_3$  and constrained entry deterrence for  $f > f_3$ .

(ii) Suppose that  $k \in (\widehat{k}, \widetilde{k}]$ . In this case, if the incumbent wants to accommodate entry, the optimal price is given by  $p_I^a$  in (12). If, in addition,  $f \leq f_1$ , the incumbent chooses between unconstrained entry accommodation and constrained entry deterrence. A comparison of (15) and (29) shows that

$$\pi_I^a - \widehat{\pi}_I^d = \frac{\left( (3t - \Delta v)^2 + 16kt\beta\Delta v \right) (t + (1 - \beta k) \Delta v) - 32\beta t^2 f}{16t\beta (t + (1 - \beta k) \Delta v)} \geq (<) 0 \text{ if } f \leq (>) f_2. \quad (\text{A3})$$

Furthermore, we have that

$$f_1 - f_2 = \frac{(t + (1 - \beta k) \Delta v) \left( 22t\Delta v + 7t^2 - (\Delta v)^2 - 32kt\beta\Delta v \right)}{32\beta t^2} \geq (<) 0 \text{ for } k \leq (>) \widetilde{k}, \quad (\text{A4})$$

implying that the parameter set given by  $f \in (f_2, f_1]$  is non-empty for all  $k \in (\widehat{k}, \widetilde{k}]$ . Thus, if  $k \in (\widehat{k}, \widetilde{k}]$ , the SPNE outcome is unconstrained entry accommodation for  $f \leq f_2$  and constrained entry deterrence for  $f \in (f_2, f_1]$ .

Suppose instead that  $f > f_1$ . In this case, if the incumbent wants to deter entry, the optimal price is  $p_I^d$  in (24). Thus, the incumbent now chooses between unconstrained entry accommodation and unconstrained entry deterrence. A comparison of (15) and (25) shows that  $\pi_I^d > \pi_I^a$  if

$$\frac{2\sqrt{2\beta t f} - t - \Delta v}{\beta} > \frac{(3t - \Delta v)^2}{16t\beta}, \quad (\text{A5})$$

or

$$8\beta t f > \left( \frac{(3t - \Delta v)^2}{16t} + t + \Delta v \right)^2, \quad (\text{A6})$$

or

$$f > \frac{(5t + \Delta v)^4}{2048\beta t^3} = f_4. \quad (\text{A7})$$

Furthermore, we have that

$$f_1 - f_4 = \frac{(22t\Delta v + 7t^2 - (\Delta v)^2 - 32kt\beta\Delta v)(42t\Delta v + 57t^2 + (\Delta v)^2 - 32k\beta t\Delta v)}{2048\beta t^3} \quad (\text{A8})$$

$$\geq (<) 0 \text{ if } k \leq (>) \tilde{k}.$$

Thus,  $\pi_I^d > \pi_I^a$ , implying that the SPNE outcome if unconstrained entry deterrence, for all  $k \in (\hat{k}, \tilde{k}]$  and  $f > f_1$ .

(iii) Suppose that  $k > \tilde{k}$ , which, since  $\tilde{k} > \hat{k}$ , means that the incumbent can accommodate entry by setting the price  $p_I^a$ . Furthermore, entry deterrence is unconstrained if  $f > f_1$ . We have already shown that unconstrained entry deterrence is more profitable than unconstrained entry accommodation if  $f > f_4$ , and from (A8) we know that  $\max\{f_1, f_4\} = f_4$  for  $k > \tilde{k}$ . Thus, the SPNE is unconstrained entry deterrence if  $k > \tilde{k}$  and  $f > f_4$ . If instead  $f \leq f_1$ , the incumbent chooses between unconstrained entry accommodation and constrained entry deterrence. But from (A3) we know that  $\pi_I^a > \hat{\pi}_I^d$  if  $f < f_2$ , and from (A4) we know that  $f_2 > f_1$  if  $k > \tilde{k}$ . Thus,  $\pi_I^a > \hat{\pi}_I^d$  if  $f \leq f_1$  and  $k > \tilde{k}$ , and we already know that  $\pi_I^a > \pi_I^d$  if  $f \in (f_1, f_4)$ . Thus, the SPNE is unconstrained entry accommodation if  $k > \tilde{k}$  and  $f \leq f_4$ .

## Proof of Proposition 2

From part (i) of Proposition 1, the incumbent chooses an entry deterring strategy that is constrained by the CE condition if  $k \leq \hat{k}$  and  $f > f_3$ . From (31) we derive

$$\frac{\partial f_3}{\partial (\Delta v)} = -\frac{(t + (1 - \beta k) \Delta v)(3(1 - \beta k)(1 - 2\beta k) \Delta v - t)}{4\beta t^2}. \quad (\text{A9})$$

It is straightforward to verify that  $\partial f_3 / \partial (\Delta v) < 0$  if  $k$  is sufficiently small. In this case, an increase in  $\Delta v$  implies that the condition  $f > f_3$  holds for a larger set of parameter values, thus increasing the scope for constrained entry deterrence.

## Proof of Proposition 3

Lemmas 1 and 2 establish the non-positive relationship between  $k$  and equilibrium drug prices within each candidate SPNE outcome. It follows from Proposition 1 that, for a given value of  $f$ , a reduction in  $k$  can lead to a switch (i) from unconstrained to constrained entry accommodation, (ii) from unconstrained to constrained entry deterrence, (iii) from unconstrained entry

accommodation to constrained entry deterrence, and (iv) from constrained entry accommodation to constrained entry deterrence. For case (i) we know that the unconstrained equilibrium prices are independent of  $k$ , while the constrained equilibrium prices are monotonically decreasing in  $k$ . From Lemma 2 we know that the same is true for case (ii). Thus, a switch from unconstrained to constrained entry accommodation or entry deterrence always leads to higher drug prices. On the other hand, a switch from (unconstrained or constrained) entry accommodation to constrained entry deterrence, i.e., cases (iii) or (iv), must necessarily imply a reduction in the price of the incumbent drug.



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